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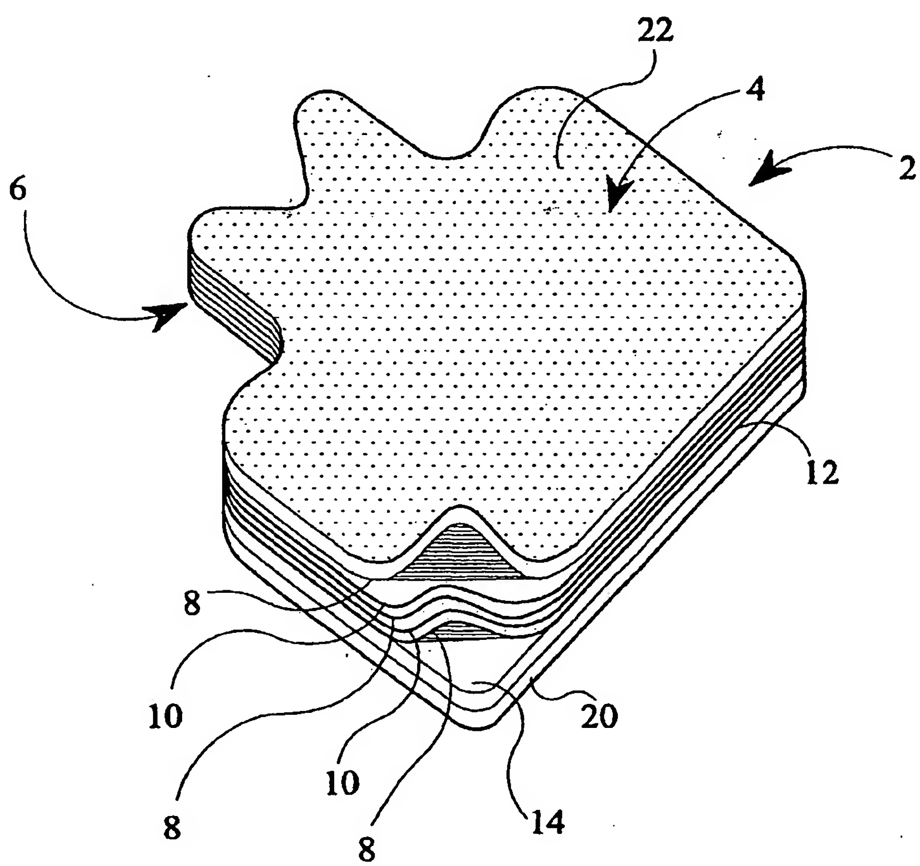

(57) Abstract: A composite flexible sheet-form material comprises a layer of fabric material selected from a para-aramide material (hereinafter referred to as aramid material), high performance polyethylene material (hereinafter referred to as HPPE material) and a poly(p-phenylene-2,6-benzo-bisoxazole) material (hereinafter referred to as PBO material), and a thermoplastic polymeric material. The thermoplastic polymeric material is applied to both major faces of the fabric material so as to encapsulate the fabric material within the polymeric material. A penetration resistant composite article can be made from a plurality of layers of the composite sheet-form material.

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COMPOSITE MATERIAL AND USE THEREOF

The present invention concerns a composite material and the use thereof. The material may be used, for example, in a flexible penetration resistant composite article, particularly for use as, or in, body armour, such as a bullet-proof vest or jacket.

Body armour is well known and may be bullet (ballistic) and/or knife (stab) resistant.

Knife resistant body armour generally comprises a metal plate, wire mesh, chain mail or rigid plastics material. Such materials are heavy, stiff and uncomfortable to wear.

Bullet resistant body armour generally comprises multiple layers of bullet resistant fabric.

Three main types of fabric are known for use in bullet resistant body armour. These are made from para-aramide fibres (generally known as aramid fibres), or high performance polyethylene (HPPE) fibres, or poly(p-phenylene-2,6-benzobisoxazole) fibres (generally known as PBO fibres).

The ballistic resistance of all three types of fabric is reduced in the presence of moisture, although with HPPE the effect is generally less than with the other types.

Although aramid and PBO fabrics are normally provided with a water-repellant finish after manufacture, performance of these fabrics is still reduced in the presence of moisture. As a further protective measure, armour panels made from these fabrics are generally enclosed in a waterproof plastics envelope. However, such an envelope, if punctured, can allow entry and

entrapment of water. Such water can 'wick' through the layers of fabric in the armour.

Body armour has traditionally been worn on land, where problems with water are not great. However, body armour is increasingly required for use on boats by customs personnel, coastguards and military special forces. Here, exposure of body armour to drenching by water may be severe and the body armour may be required to be stored in damp or wet conditions.

It is known from WO-A-97 21334 to provide a penetration-resistant material in which a fibre layer is provided at one or both sides of a polymeric continuum. A similar structure is known from WO-A-00 08411. However, neither of these structures is effective in the presence of water.

It is an object of the present invention to provide a composite material which overcomes the above problems in addition to being usable in other applications where a high-strength lightweight material is required.

The present invention is based on the finding that moisture resistance, particularly of aramid and PBO fabrics, is increased by encapsulating such fabrics with a thermoplastic polymeric material.

According to the present invention there is provided a composite flexible sheet-form material comprising a layer of fabric material selected from a para-aramide material (hereinafter referred to as aramid material), high performance polyethylene material (hereinafter referred to as HPPE material) and a poly(p-phenylene-2,6-benzobisoxazole) material (hereinafter referred to as PBO material), and a thermoplastic polymeric material applied to both major faces of the fabric material so as to

encapsulate the fabric material within the polymeric material.

The thermoplastic polymeric material may comprise a thermoplastic resin material or a thermoplastic elastomer material. Suitable materials include those derived from polyacrylic, polyacetal, polyamide, polyimide, polycarbonate, polyester, polyurethane, polyethylene, polypropylene, polysulphone, polyolefin, polyvinylchloride, polyether ether ketone, phenolic, cellulose and ionomeric resin materials.

Such materials include metallocene polyethylene resins and metallocene elastomers such as EXCEED and EXACT supplied by Exxon, ionomeric resins such as SURLYN supplied by Du Pont and IOTEK supplied by Exxon, thermoplastic polyester elastomers and polyester butylene terephthalate resins such as HYTREL and CRASTIN supplied by Du Pont, various nylon homopolymers and copolymers such as ZYTEL supplied by Du Pont, polyetherimide resin such as PEBAX supplied by Elf Atochem, and polystyrene-polybutadiene-polystyrene block copolymers such as KRATON supplied by Shell Chemical Company.

The ionomer resin material may be derived from at least one ethylene/methacrylic acid copolymer.

The thermoplastic polymeric material may incorporate particulate reinforcing material dispersed therein, such as carbon, metal(s) and/or ceramic(s).

The thermoplastic polymeric material may have a thickness from about 30 microns to about 125 microns, for example from about 40 to about 125 microns, and preferably has a thickness of about 60 to 75 microns.

The thermoplastic polymeric material may be applied in the form of a film impregnated into the fabric material.

The fabric material, which may be made from fibre in the form of thread or yarn, may be woven or knitted, or may be arranged as overlying layers to produce a plied arrangement. Such overlying arrangement may comprise two or more layers of fibre material, with the fibre material in each layer being arranged substantially unidirectionally and with the fibre material in adjacent layers being substantially at right angles to one another.

It may be preferred for the sheet-form material to comprise a woven fabric which may be woven from a yarn of low to mid weight and may comprise a plain weave or a Panama weave, which may be of densely woven form.

According to another aspect of the present invention there is provided a flexible penetration resistant composite article comprising a plurality of layers of composite sheet-form material as defined hereinabove.

The layers of the sheet-form material may be secured together, such as at peripheral edges thereof, such as by means of stitching, thermal fusing, or an adhesive. Alternatively, the layers may be separate.

The composite article may have a peripheral edge which is coated with a waterproof adhesive material, such as a neoprene adhesive, which may be of two-part form.

Alternatively, or additionally, the composite article may have a peripheral edge to which a tape is adhered.

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The composite article may be provided with a surrounding envelope, which may be of mesh form, particularly a fine mesh form.

The composite article may be employed as, or in, body armour, such as for resisting bullet or knife penetration, and may be incorporated in a jacket or vest for wearing by a user.

The composite article may additionally be provided with a residual kinetic energy attenuating shield in contact with a face thereof which is to be arranged adjacent to a body of a user. Such shield is sometimes referred to as a trauma shield and may comprise a plurality of layers of the sheet-form material. Such plurality of layers may be adhered together, such as by stitching.

The composite article may be provided, adjacent one or both opposite faces thereof with a sheet of foam material, suitably of closed cell form and suitably of plastics or rubber. Such foam material may serve to provide buoyancy, when employed with a jacket or vest for wearing by a user in water, and/or may provide enhanced comfort to a user.

The provision of the thermoplastic polymeric encapsulation provides enhanced penetration resistance to the aramid, HPPE or PBO material of the layers of the sheet-form material, especially when wet, whereby performance of the composite article is substantially maintained, such as when used by a person as, or in, body armour and subjected to, or immersed in, water.

However, body armour produced from such sheet-form material alone can be found to be too stiff, bulky and heavy for use or may have other disadvantages for particular applications. Such problems can in some

circumstances be overcome by providing a layered construction employing alternating layers, or groups of layers, of aramid, HPPE or PBO fabric sheet-form material impregnated with thermoplastic polymeric material, and a further sheet-form material of fabric comprising HPPE fibres.

The composite article may have first and last layers, or first and last groups of layers, of the alternating layers, or groups of layers, both comprising the thermoplastic polymeric material encapsulated first-mentioned sheet-form material.

The further sheet-form material may be of fabric form comprising fibre material.

The fibre material of the further sheet-form material, which may be in the form of thread or yarn, may be woven or knitted to produce the fabric form, or may be arranged as overlying layers to produce a plied arrangement for the fabric form. Such overlying arrangement may comprise two or more layers of fibre material, with the fibre material in each layer being arranged substantially unidirectionally and with the fibre material in adjacent layers being substantially at right angles to one another.

It may be preferred for the further sheet-form material to comprise a fabric having the plied arrangement of fibre material.

The alternating layers, or groups of layers, of the first-mentioned and further sheet-form materials may be secured together, such as at peripheral edges thereof, such as by means of stitching, thermal fusing, or an adhesive.

The flexible penetration resistant composite article comprising the first-mentioned and further sheet-form materials is advantageous in that, as a result of the HPPE layers with the layers of thermoplastic polymeric encapsulated aramid, HPPE or PBO material, it is light in weight and flexible relative to comparative prior art articles providing corresponding penetration resistance. The provision of the thermoplastic polymer on the major surfaces of the first sheet form material, particularly of aramid material, provides modified friction between the adjoining surfaces of the first-mentioned and further sheet-form materials. The friction obtained is similar to that which would be obtained between two sheets of HPPE fabric and higher than that between two sheets of aramid fabric material. Improved performance of the composite article results.

For a better understanding of the present invention and to show more clearly how it may be carried into effect, reference will now be made, by way of example, to the accompanying drawings in which:

Figure 1 is a cut-away perspective view of one embodiment of a flexible penetration resistant article according to the present invention, in the form of body armour;

Figure 2 is a perspective view of a residual kinetic energy attenuating shield for optional use with the article of Figure 1; and

Figure 3 is a cut-away perspective view of another embodiment of a flexible penetration resistant article according to the present invention, in the form of body armour.

Referring to Figure 1, a flexible penetration resistant composite article is provided in the form of body armour

2, for wearing by a person and having a front face 4 for presenting towards an attacker and arranged for receiving bullets from a gun, or thrusts from a knife. A rear face 6 of the body armour 2 is arranged for contacting the body of the person wearing the body armour 2.

The body armour 2 is made up of alternating layers 8, 10 of flexible sheet-form materials.

The layers 8 comprise a first flexible sheet-form material comprising an aramid (para-aramide) material, an HPPE (high performance polyethylene) or a PBO (poly(p-phenylene-2,6-benzobisoxazole)) fabric material. Such fabric material is arranged to be coated on both major surfaces thereof with a thermoplastic polymeric material so as to encapsulate the fabric material within the polymeric material.

The thermoplastic polymeric material may be selected from a thermoplastic resin material or a thermoplastic elastomer material. Suitable materials include those derived from polyacrylic, polyacetal, polyamide, polyimide, polycarbonate, polyester, polyurethane, polyethylene, polypropylene, polysulphone, polyolefin, polyvinylchloride, polyether ether ketone, phenolic, cellulose and ionomeric resin materials.

Such materials include metallocene polyethylene resins and metallocene elastomers such as EXCEED and EXACT supplied by Exxon, ionomeric resins such as SURLYN supplied by Du Pont and IOTEK supplied by Exxon, thermoplastic polyester elastomers and polyester butylene terephthalate resins such as HYTREL and CRASTIN supplied by Du Pont, various nylon homopolymers and copolymers such as ZYTEL supplied by Du Pont, polyetherimide resin such as PEBAX supplied by Elf Atochem, and polystyrene-

polybutadiene-polystyrene block copolymers such as KRATON supplied by Shell Chemical Company.

The ionomer resin material may be derived from at least one ethylene/methacrylic acid copolymer.

The thermoplastic polymeric material may incorporate particulate reinforcing material dispersed therein, such as carbon, metal(s) and/or ceramic(s).

The thermoplastic polymeric material is suitably provided in the form of a film of thickness between about 30-40 microns and about 125 microns, and preferably about 60 to 75 microns. The film material suitably comprises Surlyn (Registered Trade Mark) ionomer resin, supplied by Du Pont, and is applied to the sheet-form material of the layers 8 by hot pressing, such as at a temperature of about 160 degrees Celsius, at a pressure of about 10 bars, for about 10 to 15 minutes. In this way, the polymeric material is driven deeply into the interstices of the fabric, filling the spaces between individual fibres. Essentially all the air in the fabric is expelled and replaced with polymeric material such that the fabric material is essentially impregnated with the polymeric material.

The film material can be applied by pressing or by rolling. By way of example, when applying the film material by pressing a stack of sheets is assembled in a press by first applying a sheet of release material to the bed of the press, applying a sheet of film material, applying a sheet of aramid/HPPE/PBO fabric material, applying a further sheet of film material, applying a sheet of release material and so on until a suitable stack has been assembled which may comprise fifty or more sheets of aramid/HPPE/PBO fabric material each sandwiched between two sheets of film material. The stack is then

heated throughout to the required temperature and compressed at the desired temperature for the desired time. At the temperatures and pressures indicated above, the film material becomes sufficiently fluid to penetrate completely through the fabric material to form a single entity within which the fabric material is encapsulated and completely surrounded.

Aramid material for the first sheet-form material used for the layers 8 suitably comprises Kevlar (Registered Trade Mark) fibres, supplied by Du Pont, or Twaron (Registered Trade Mark) fibres, supplied by Akzo Nobel. The fibres of aramid material are preferably of low to mid weight and are densely woven into a fabric in the form of a plain or Panama weave.

As one example, an aramid fabric is woven using 93 tex fibre yarn at a density of 10.7 threads/cm in both warp and weft and has a woven weight of 200 grams per square metre.

As another example, an aramid fabric is woven using 67 tex fibre yarn at a density of 12.2 threads/cm in both warp and weft and has a woven weight of 160 grams per square metre.

As a further example, an aramid fabric is woven using 44 tex fibre yarn at a density of 13.8 threads/cm in both warp and weft and has a woven weight of 125 grams per square metre.

PBO material for the first sheet-form material used for the layers 8 suitably comprises Zylon (Registered Trade Mark) fibres, supplied by Toyobo Co. Ltd.

By way of example, a PBO fabric is woven using 110 tex fibre yarn at a density of 8.5 threads/cm in both warp

and weft and has a woven weight of 190 grams per square metre.

By way of further example, a PBO fabric is woven using 55.5 tex fibre yarn at a density of 11.8 threads/cm in both warp and weft and has a woven weight of 130 grams per square metre.

It is not essential that the fabric of either aramid or PBO materials be woven. A knitted fabric could be considered with either material and also a plied fabric in which fibre threads or yarns are laid on top of each other in two or more layers at right angles to one another.

The layers 10, which in the illustrated embodiment alternate with the layers 8, comprise a second sheet-form material comprising HPPE (high performance polyethylene). The second sheet-form material is a fabric made up of fibres of HPPE material. The fabric may be woven or knitted from the fibres of HPPE material but is preferably of plied construction, comprising two layers of unidirectional HPPE fibre threads or yarns at right angles to one another, secured with a light resin and with a thermoplastic protective outer film.

Suitable HPPE fibres are Dyneema (Registered Trade Mark) fibres, supplied by DSM High Performance Fibers B.V. and Spectra (Registered Trade Mark) fibres, supplied by Allied Signal Inc.

The body armour 2 suitably comprises sixteen in number of layers 8 and fifteen in number of layers 10, although variations are possible according to design requirements.

If desired, instead of providing alternating single layers 8 and 10, groups of layers 8 could be alternated

with groups of layers 10. For example, a group of fifteen layers 10, comprising the HPPE fabric, could be sandwiched between two groups of layers 8, each having eight layers, and comprising the thermoplastic polymer encapsulated aramid, HPPE or PBO fabric. However, such a construction may not be so effective, particularly against a bullet fired at point blank range.

It is preferred that a layer 8, or a group of layers 8, of the thermoplastic polymer encapsulated aramid, HPPE or PBO fabric material be provided at the front and the back of the stack of alternating layers 8 and 10.

The stack of layers 8 and 10 is then cut to form a required shape for the body armour 2, using a band-knife, or similar knife. Friction of the cutting blade may be used to cause edges 12 of the stack of layers 8 and 10 to partly fuse together to bond the layers to one another. Further heat, such as from a heated iron, can be provided to the edges 12, to improve fusing and bonding of the layers 8 and 10.

Alternatively, the stack of layers 8, 10 could be stitched together at the edges, or the edges 12 could be covered with an adhesive and a tape.

It is preferred that the edges 12 should be generously coated with a waterproof adhesive material, such as a neoprene adhesive of two-part form.

As an option, a residual kinetic energy attenuating (trauma) shield 14 can be applied in contact with the rear face 6 of the body armour 2. Such a shield 14 minimises or reduces blunt injury to a user of the body armour 2 caused by residual kinetic energy passing through the body armour 2 upon arrest of a bullet by the armour.

As shown in Figure 2, the shield 14 comprises a small number (for example five) of layers 16 of thermoplastic polymer encapsulated aramid, HPPE or PBO fabric material, suitably joined together by stitching 18. The stitching 18 suitably comprises 50 mm spaced cross-stitching.

When the layered shield 14 is provided, a corresponding number of layers 8, 10 may be removed from the armour construction.

In order to provide comfort to a user of the body armour 2 and also to provide buoyancy to the user when the body armour 2 is worn submerged in water, a layer 20 of closed cell foam material, such as of rubber or plastics, can be provided at the rear surface 6 of the body armour 2, against the shield 14, where provided.

The resulting construction of body armour 2 is suitably enclosed in a protective and durable fine mesh envelope 22. This is preferable to a plastics material envelope, such as of polyurethane-coated nylon, since it allows drainage of water and ventilation for drying, after submersion of the body armour in water. A plastics material, if perforated as a result of damage, would allow water to be trapped inside the envelope.

The resulting body armour 2 may be fitted into a well known form of jacket or vest (not shown) for wearing by a user.

The body armour 2 finds particular application in severe wet conditions, such as experienced by boat crews, such as customs personnel, coastguards and other naval and special military forces. However, it is equally applicable for use by wearers on land, such as police officers. It is of especial usefulness because of its high level of protection and relatively light weight.

When the body armour 2 is used in life jackets or vests, the sheet 20 of closed cell foam provides buoyancy. The jacket or vest may also incorporate an inflatable stole for buoyancy and may also incorporate crotch straps for securing the jacket or vest when worn in water. It may also incorporate one or more pockets and/or pouches and/or lifting beckets, the latter being used for winching a wearer from the water.

In a test, the body armour 2 met the requirements of the PSDB Ballistic Body Armour Standard (1995) at level HG2 (High Handgun/Carbine Level 2). Surprisingly, it also met the requirements of the PSDB Stab Resistance Standard for Body Armour (1999) at level KR2 (Knife Resistance Level 2).

The body armour 2 shown in Figure 3 is similar to that shown in Figure 2 except there are no layers 10. All the layers of the body armour 2 of Figure 3 are composed of layers 8 comprising an aramid, HPPE or a PBO fabric material coated on both major surfaces thereof with a thermoplastic polymeric material to encapsulate the fabric material within the polymeric material as described above in relation to Figure 1. Surprisingly, the encapsulated aramid/HPPE/PBO material performs about 25 percent better than unencapsulated material in comparative tests. It has been found that the fibres do not wick even when immersed in water for one hour and therefore it is not essential to apply a waterproofing agent (such as the neoprene described above), nor is it necessary to secure the different layers together.

Clearly the sheet-form material comprising aramid/HPPE/PBO fabric material coated with thermoplastic polymeric material to encapsulate the fabric material within the polymeric material can be used in many applications other than body armour.

The present invention is illustrated by the following examples:

Example 1 (Comparative)

A fabric was woven using 93tex aramid fibre yarn at a density of 10.7 threads/cm in both warp and weft and had a woven weight of 200 grams per square metre. The woven fabric was scoured and dried. This fabric represents a woven aramid fabric well known in the ballistic body armour art.

Five test samples of body armour were constructed with the woven fabric. Each test sample was in the form of 29 layers of the fabric cut into 400 mm squares. The squares in each test sample were laid together and sewn in a quilt stitch pattern over the entire surface (such quilt stitching is well known in the art for preventing penetration of bullets fired at target samples from acute angles to the face of the armour under test). This is a common and well known armour construction employing woven aramid fabric.

On the rear face (opposite the attack face) of the test samples there was positioned a 10 mm thick sheet of closed cell buoyancy foam of ethylene-vinyl-acetate (EVA) and nitrile rubber supplied by Vita Industrial Polymers under the trade mark VITACELL.

The test samples were weighed and the areal density was determined at 6.155 kg/m^2. The test samples were then marked Sample No. 1, 2, 3, 4 and 5, respectively.

Samples Nos. 1 and 2 were preconditioned in a manner well known in the art and were mounted upon plasticine for shooting as prescribed in PSDB Ballistic Armour Standard (1995) for Handgun Level 2 (HG2). Sample No. 1 was shot

with six rounds of 9 mm calibre bullets to the precise specification for bullet manufacture, bullet construction and bullet velocity, and at the placement pattern and angles prescribed for HG2. Similarly, Sample No. 2 was shot with six rounds of .357 inch calibre bullets.

As would be expected, both samples successfully arrested all the bullets. No bullet passed through either sample and measurement of the impressions in the plasticine behind each bullet strike revealed all impressions to be less than the 25 mm maximum depth permitted by the PSDB HG2 standard.

Samples Nos. 3 and 4 were weighted and totally immersed in water for 5 minutes. Immediately thereafter the samples were mounted and shot in precisely the same manner as for Samples Nos. 1 and 2. None of the bullets was arrested by either Sample No. 3 or Sample No. 4 and all bullets passed through the two samples.

Sample No. 5 was preconditioned and mounted on foam for stab resistance testing as prescribed in PSDB Stab Resistance Standard for Body Armour (1999) for Knife Resistance Levels 1 and 2 (KR1 and KR2). The sample was subjected to multiple stabbings precisely in accordance with the PSDB procedures and with equipment as specified in the standard. All stabbings penetrated through the sample in excess of the maximum permitted penetration of the PSDB standard for both KR1 and KR2.

Further stabbing tests were carried out on Sample No. 5 in precisely the same manner as described above. However, for each additional test a sample of a typical knife-resistant body armour insert material known in the art was placed on the attack face of the sample. Insert materials were chosen that, when used in conjunction with an aramid construction of the type of Sample No. 5, were

known to resist knife-penetration to the level of PSDB KR2 (or the former and recently superseded PSDB KR42). The combination of the sample and the insert were weighed each time and the areal density was determined. The following inserts were used and the following areal densities were determined:

Two thicknesses of 301 stainless steel cold rolled sheet each of 0.8 mm thickness with a hardness of 560VPN, supplied by Lee Steel Strip. The combined areal density with the aramid was 11.14 kg/m^2.

Three thicknesses of 0.7% carbon steel galvanised cable and nylon fabric of 1.7 mm thickness with a cable breaking strength of 300 N/mm, supplied by NV Bekaert SA. The combined areal density with the aramid was 10.55 kg/m^2.

Two thicknesses of stainless steel knitted wire mesh, supplied by Knitwire, in combination with one thickness of Kevlar felt, supplied by Duflot, total thickness of 4.5mm. The combined areal density with the aramid was 9.25k/m2.

No stabbings penetrated through the combined samples in excess of the maximum permitted penetration of the PSDB standard for both KR1 and KR2.

Example 2

Fabric of the same specification as in Example 1 was coated on both sides in the manner described hereinabove with SURLYN ionomer resin to encapsulate the fabric material within the polymeric material. The SYRLYN ionomer resin had a thickness of 75 microns, a flexural modulus of 40 MPa and an elongation at break of 525%.

From this encapsulated material five further samples were made with 24 (as compared with 29 above) layers of encapsulated material plus a single layer of buoyancy foam. The samples were weighed and the areal density determined at 8.395 kg/m^2. The test samples were then marked Sample No. 6, 7, 8, 9 and 10, respectively.

Samples Nos. 6 to 10 were then subjected to both shooting and stabbing tests in precisely the same manner as for Samples 1 to 5 described above, except that Samples Nos. 8 and 9 to be wetted were weighted and totally immersed in water for one hour prior to shooting.

All the bullets were successfully arrested by all four of Samples Nos. 6 to 9. There were no penetrations by bullets of either calibre through any of the samples. Measurements were taken of the impressions in the plasticine behind each bullet strike and all were found to be below the maximum depth of 25 mm permitted by PSDB HG2. Further, there were no stabbings through Sample No. 10 in excess of the permitted penetrations for KR1. More surprisingly, there were no stabbings through Sample No. 10 in excess of the permitted penetrations for the more demanding level of KR2.

Although the areal density of the samples of Example 2 is somewhat higher than that of Samples 1 to 5 of Example 1, the areal density of the samples of Example 2 is lower than the combined samples of Example 1 capable of resisting a knife attack. In addition the samples of Example 2 demonstrate the benefits of resistance to bullet penetration when the armour is thoroughly wet and provide a high inherent resistance to knife stabbing.

Further, because the armour is made with a single material the resulting armour is significantly less expensive than equivalent performance conventional

complex stab-resistant materials (such as linked platelets, chain mail, knitted wire embedded in felt and the like). Moreover, conventional stab-resistant armours require an additional ballistic material which adds further to the cost of such conventional armours.

A number of additional shots of bullets of .44 inch Magnum calibre as specified for HG2 were made on free spaces between previous shots to the wetted Samples Nos. 8 and 9. All the bullets were successfully arrested and there were no penetrations of bullets through the armour. Measurements were taken of the impressions in the plasticine behind each bullet strike and, while it would not have been expected that the depth of impressions would have been below the maximum depth of 25 mm permitted by PSDB HG2, the depths of the impressions were surprisingly low with the greatest depth being 34 mm.

Example 3

Encapsulated material of the same specification as in Example 2 was used to make five further samples with 20 (as compared with 24 above) layers of encapsulated material plus a single layer of buoyancy foam. The samples were weighed and the areal density determined at 6.950 kg/m^2. The test samples were then marked Sample No. 11, 12, 13, 14 and 15, respectively.

Samples Nos. 11 to 15 were then subjected to both shooting and stabbing tests in precisely the same manner as for Samples 1 to 5 described above, except that Samples Nos. 13 and 14 to be wetted were weighted and totally immersed in water for one hour prior to shooting.

Surprisingly, all the bullets were successfully arrested by all four of Samples Nos. 11 to 14. There were no penetrations by bullets of either calibre through any of

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the samples. Measurements were taken of the impressions in the plasticine behind each bullet strike and all were found to be below (although some only slightly below) the maximum depth of 25 mm permitted by PSDB HG2. Also surprisingly, there were no stabbings through Sample No. 15 in excess of the permitted penetrations for KR1. Further, the stabbings through Sample No. 15 were only very slightly in excess of the permitted penetrations for the more demanding level of KR2.

Example 4

Encapsulated material of the same specification as in Example 2 was used to make five further samples with 16 (as compared with 20 above) layers of encapsulated material plus a single layer of buoyancy foam. The samples were weighed and the areal density determined at 5.610 kg/m^2. The test samples were then marked Sample No. 16, 17, 18, 19 and 20, respectively.

Samples Nos. 16 to 20 were then subjected to both shooting and stabbing tests in the same manner as for Samples 1 to 5 described above, except that the velocity of the bullet shots was lowered to conform to those specified in PSDB HG1 (as compared with HG2) and except that Samples Nos. 18 and 19 to be wetted were weighted and totally immersed in water for one hour prior to shooting.

Very surprisingly, all the bullets were successfully arrested by all four of Samples Nos. 16 to 19. There were no penetrations by bullets of either calibre through any of the samples. Measurements were taken of the impressions in the plasticine behind each bullet strike and all were found to be below the maximum depth of 25 mm permitted by PSDB HG1. Also surprisingly, there were no

stabbings through Sample No. 20 in excess of the permitted penetrations for KR1.

Example 5

A fabric was woven using a 110tex PBO fibre yarn at a density of 8.5 threads/cm in both warp and weft and had a woven weight of 190 grams per square metre. The woven fabric was scoured and dried. Some of the fabric was coated on both sides in the manner described hereinabove with SURLYN ionomer resin to encapsulate the fabric material within the polymeric material. The SURLYN ionomer resin had a thickness of 75 microns, a flexural modulus of 40 MPa and an elongation at break of 525%.

From both unencapsulated and encapsulated PBO fabric a range of test samples of body armour were constructed with 24 layers plus one single layer of buoyancy foam. The samples were weighed and areal densities determined of 4.62 kg/m^2 for unencapsulated fabric and 7.86 kg/m^2 for encapsulated fabric.

The samples were subjected to shooting tests both wet and dry in the same way as the samples in Example 2 described above. The wet samples were immersed for one hour before shooting. The samples were subjected to shooting tests with both 9 mm and .357 inch Magnum bullets fired in accordance with the requirements for PSDB HG2. All the bullets were successfully arrested by samples made from dry unencapsulated fabric but passed through samples made from wet unencapsulated fabric. In contrast, all the bullets were successfully arrested by samples made from encapsulated fabric, both wet and dry.

Measurements were taken of the impressions in the plasticine behind each arrested bullet strike. However,

not all the impressions were below the maximum permitted depth of 25 mm for PSDB HG1 and HG2 standards.

The samples were also subjected to multiple stabbings in accordance with the requirements of PSDB KR1 and KR2. Knife stabbings penetrated samples made from the unencapsulated fabric in excess of the permitted maximum penetrations for PSDB KR1 and KR2, but were successfully prevented from penetrating samples made from the encapsulated fabric in excess of the permitted maximum penetrations for PSDB KR1, but were just in excess of the permitted maximum penetrations for KR2.

Example 6

Encapsulated material of the same specification as in Example 2 was used to make a further sample with the encapsulated material alternating with layers of HPPE material sold under the Trade Mark DYNEEMA UD SB2 to provide a total of 27 layers (14 layers of encapsulated aramid and 13 layers of HPPE). Behind this was placed an additional armour piece of 5 layers of encapsulated aramid with the pieces sewn together with a quilt stitch of 50 mm spacing over the entire surface. A layer of 10 mm closed cell EVA/nitrile rubber buoyancy foam was placed behind the armour on the wearer's body side. The sample was weighed and the areal density determined at 8.630 kg/m^2.

The sample was weighted and totally immersed in water for one hour. On removal from the water the sample was allowed to drain for 3 minutes before being mounted upon a plasticine block as prescribed in the PSDB test procedures. The sample was shot with bullets of calibres of 9 mm, .357 inch Magnum and .44 inch Magnum in the manner and at the velocities prescribed for PSDB HG2.

All the bullets were successfully arrested by the sample. There were no penetrations by bullets of any calibre through the sample. Measurements were taken of the impressions in the plasticine behind each bullet strike and all were found to be below the maximum depth of 25 mm permitted by PSDB HG2. Moreover, the sample was also subjected to stabbing tests as described in Example 1 above and there were no stabbings through the sample in excess of the permitted penetrations for KR2.

CLAIMS

1. A composite flexible sheet-form material comprising a layer (8) of fabric material selected from a para-aramide material (hereinafter referred to as aramid material), high performance polyethylene material (hereinafter referred to as HPPE material) and a poly(p-phenylene-2,6-benzobisoxazole) material (hereinafter referred to as PBO material), and a thermoplastic polymeric material applied to both major faces of the fabric material so as to encapsulate the fabric material within the polymeric material.

2. A composite material as claimed in claim 1, characterised in that the thermoplastic polymeric material is selected from a thermoplastic resin material and a thermoplastic elastomer material.

3. A composite material as claimed in claim 2, characterised in that the thermoplastic polymeric material is selected from polyacrylic, polyacetal, polyamide, polyimide, polycarbonate, polyester, polyurethane, polyethylene, polypropylene, polysulphone, polyolefin, polyvinylchloride, polyether ether ketone, phenolic, cellulose and ionomeric resin materials.

4. A composite material as claimed in any preceding claim, characterised in that the thermoplastic polymeric material incorporates particulate reinforcing material dispersed therein.

5. A composite material as claimed in claim 4, characterised in that the particulate reinforcing material is selected from carbon, metal(s) and ceramic(s) and mixtures thereof.

6. A composite material as claimed in any preceding claim, characterised in that the thermoplastic polymeric material has a thickness of from about 30 microns to about 125 microns.

7. A composite material as claimed in claim 6, characterised in that the thermoplastic polymeric material has a thickness of from about 40 microns to about 125 microns.

8. A composite material as claimed in claim 6 or 7, characterised in that the polymeric thermoplastic material has a thickness of about 75 microns.

9. A composite material as claimed in claim 6 or 7, characterised in that the thermoplastic polymeric material has a thickness of about 60 microns.

10. A composite material as claimed in any preceding claim, characterised in that the thermoplastic polymeric material is in the form of a film impregnated into the fabric material.

11. A composite material as claimed in any preceding claim, characterised in that the fabric material is selected from woven, knitted and plied fabrics.

12. A composite material as claimed in claim 11, characterised in that the plied fabric comprises two or more layers of fibre material, with the fibre material in each layer being arranged substantially unidirectionally and with the fibre material in adjacent layers being substantially at right angles to one another.

13. A flexible penetration resistant composite article comprising a plurality of layers (8) of composite sheet-form material as claimed in any one of claims 1 to 12.

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14. A flexible penetration resistant composite article as claimed in claim 13, characterised in that the layers (8) of the sheet-form material are secured together.

15. A flexible penetration resistant composite article as claimed in claim 14, characterised in that the layers (8) are secured together at peripheral edges thereof.

16. A flexible penetration resistant composite article as claimed in claim 13, characterised in that the layers (8) of the sheet-form material are separate.

17. A flexible penetration resistant composite article as claimed in any one of claims 13 to 16, and including a surrounding envelope (22).

18. A flexible penetration resistant composite article as claimed in any one of claims 13 to 17 and including, adjacent one or both opposite faces thereof, a sheet of foam material (20).

19. A flexible penetration resistant composite article as claimed in claim 18, characterised in that the foam material (20) is of closed cell form.

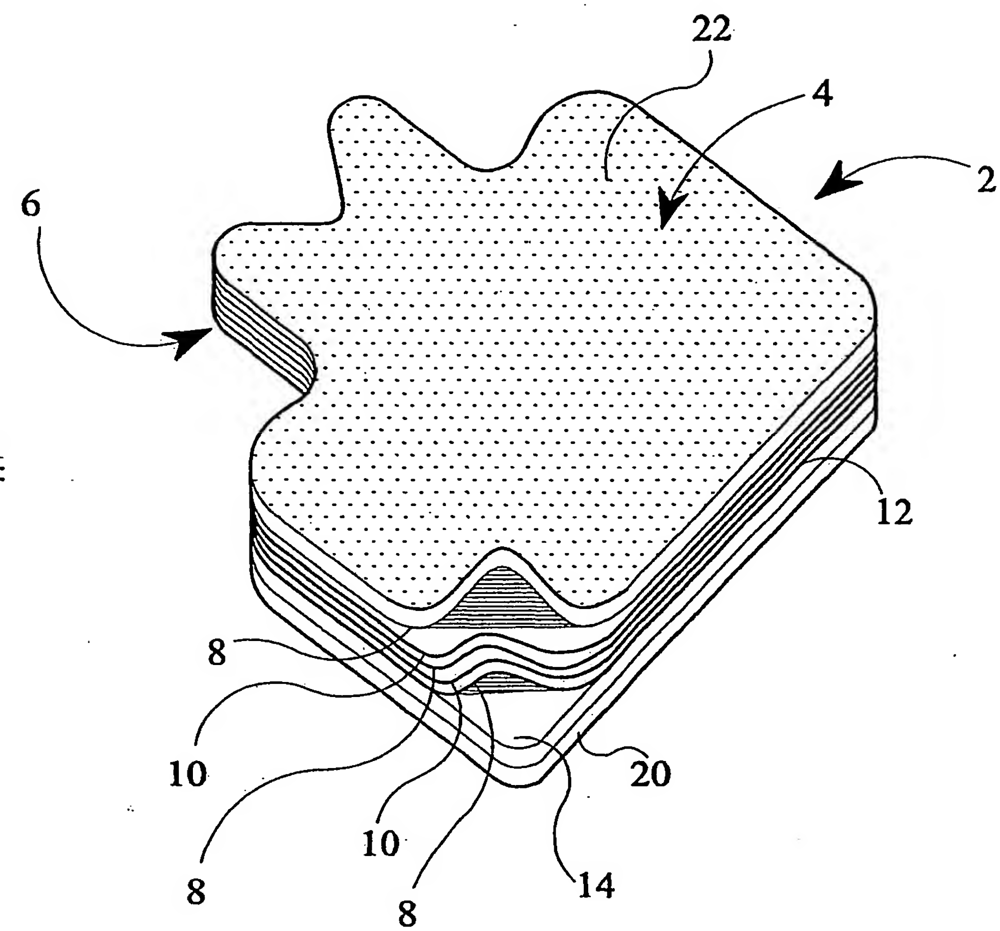

FIG 1

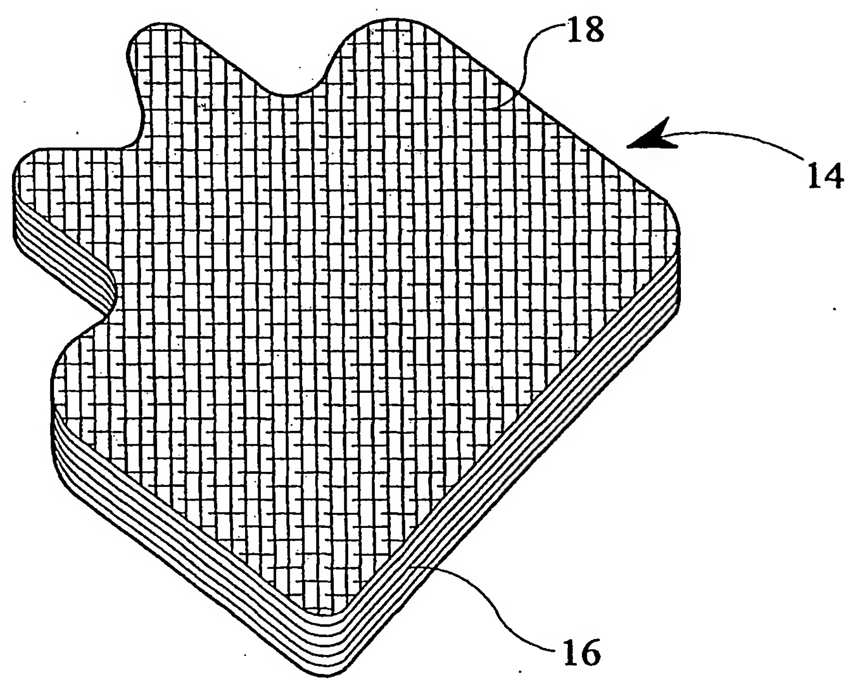

FIG 2

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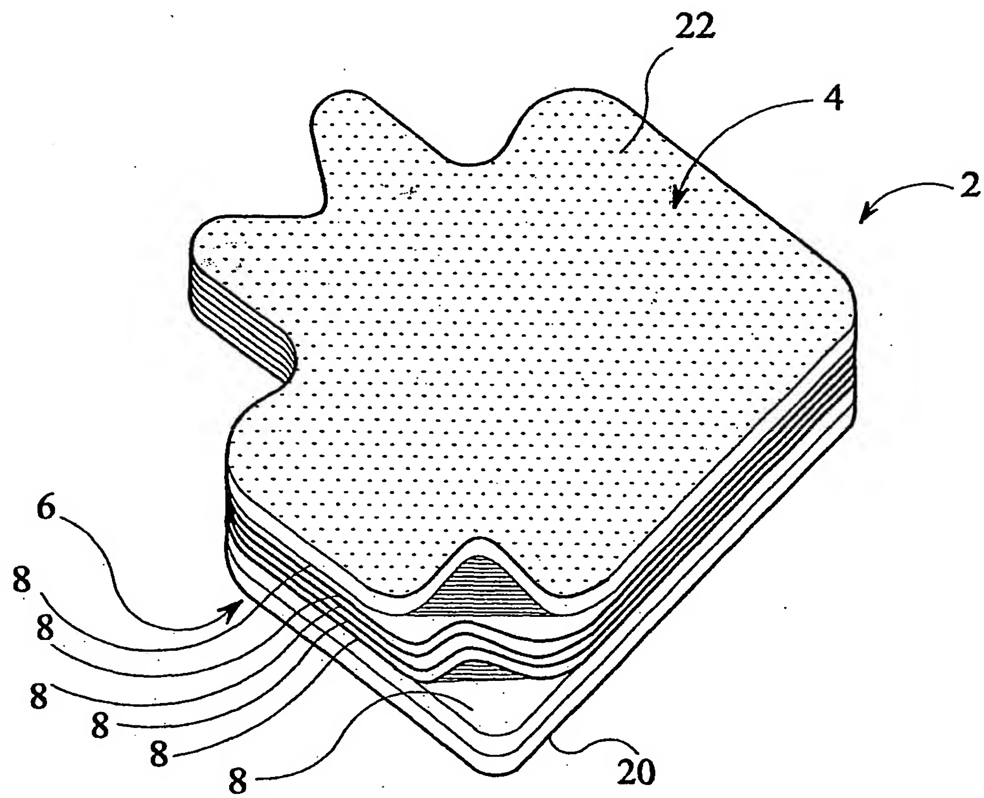
FIG 3



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INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 01/02518

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 B32B27/32 B32B27/34 B32B27/28

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 B32B F41H

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, CHEM ABS Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,X	WO 00 55565 A (SIMULA INC) 21 September 2000 (2000-09-21) claims 1,5-10,13,15,19 page 5, line 14 - line 21 page 7, line 13 - line 19 page 10, line 16 -page 11, line 3 page 12, line 13 -page 14, line 11	1,2, 11-14,17
X	US 6 047 399 A (BACHNER JR THOMAS E) 11 April 2000 (2000-04-11) claims 1,2,5,8,9 column 9, line 4 - line 25	1-3, 11-14,17

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

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Date of the actual completion of the international search	Date of mailing of the international search report
9 August 2001	03/09/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Girard, S

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 01/02518

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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X	EP 0 545 182 A (WINTER OPTIK) 9 June 1993 (1993-06-09) claims 1,3-6,8	13,14, 18,19

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